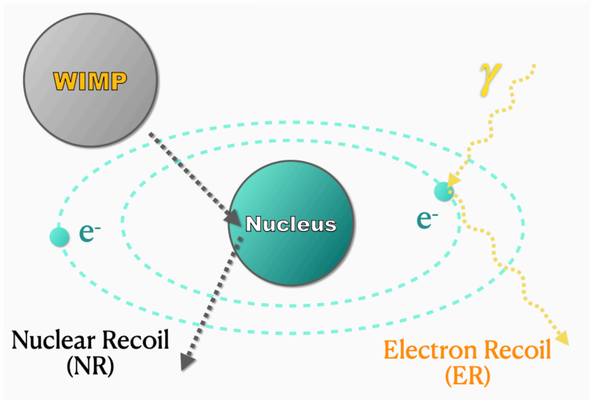
Latest Results from the LUX-ZEPLIN (LZ) Experiment

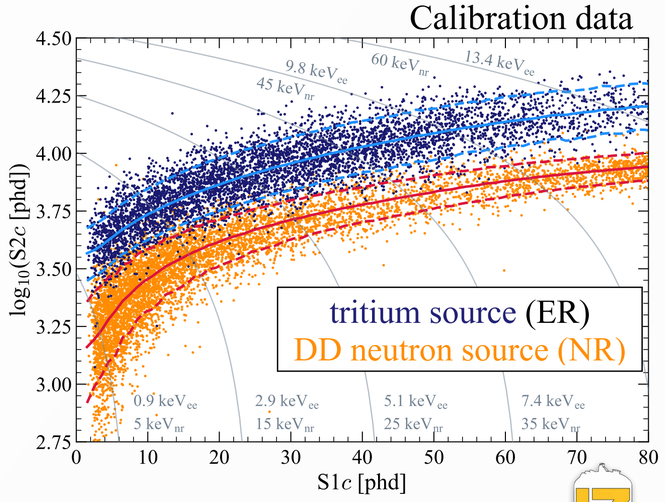
LIDINE 2025

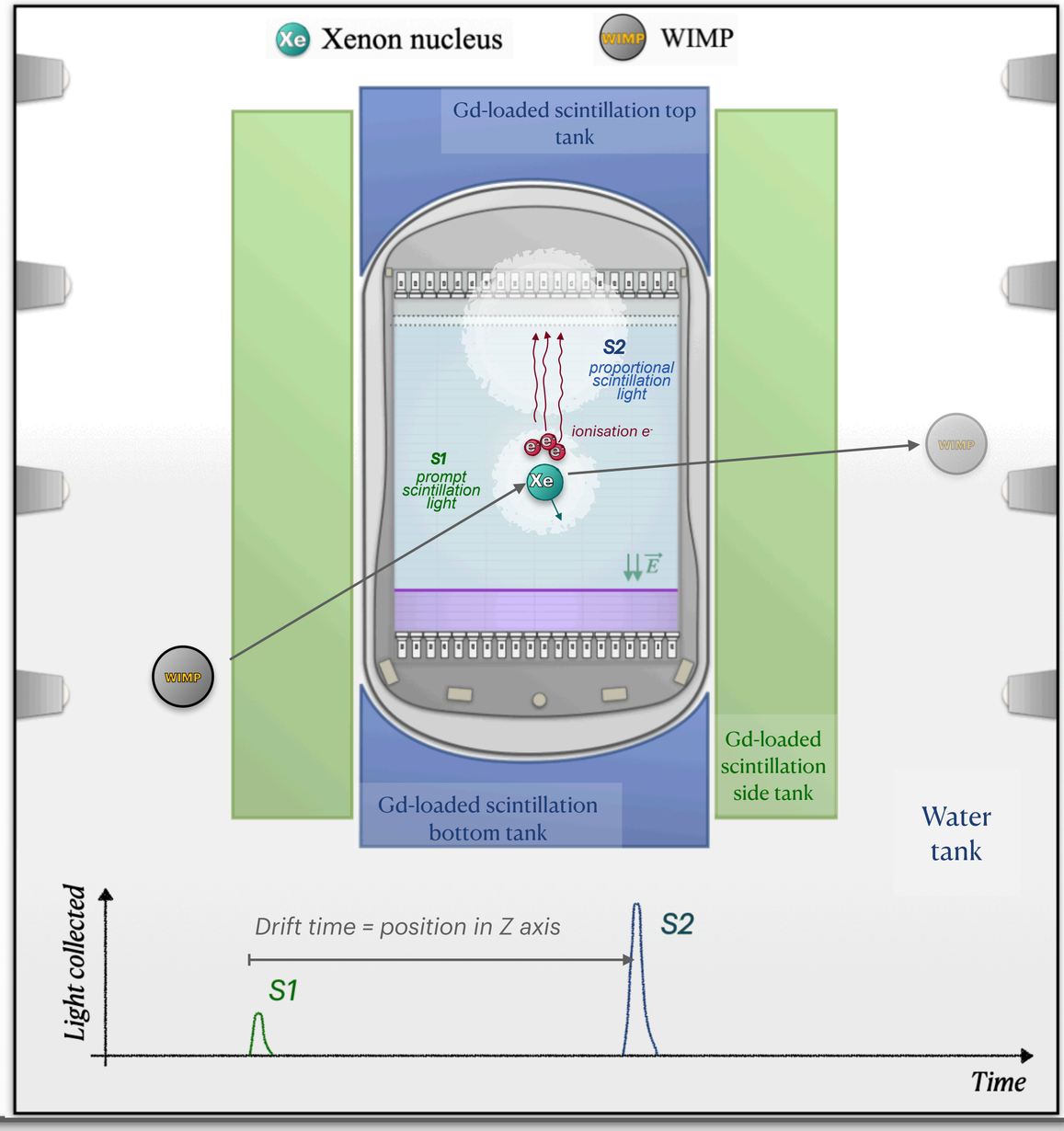
Alberto Uson
on behalf of the LZ Collaboration
21/10/2025

The LUX-ZEPLIN (LZ) detector

- Optimised for searching **WIMP**s with masses above ~3 GeV/c^2
- Sensitive to additional processes, including BSM physics: $0\nu\beta\beta$, axions, etc
- 7t active mass **dual-phase xenon electroluminescent-TPC** at the Sanford Underground Research Facility (SURF), Lead, South Dakota
- Events reconstructed combining scintillation (S1) and ionisation (S2)
- Excellent 3D position reconstruction (~mm)
- Single Scatter (SS) vs Multiple Scatter (MS) interactions discrimination
- S2/S1 ratio indicates the type of interaction:
  - Nuclear recoils (**NR**) in xenon mostly from WIMPs
  - Most backgrounds are Electron Recoils (**ER**)



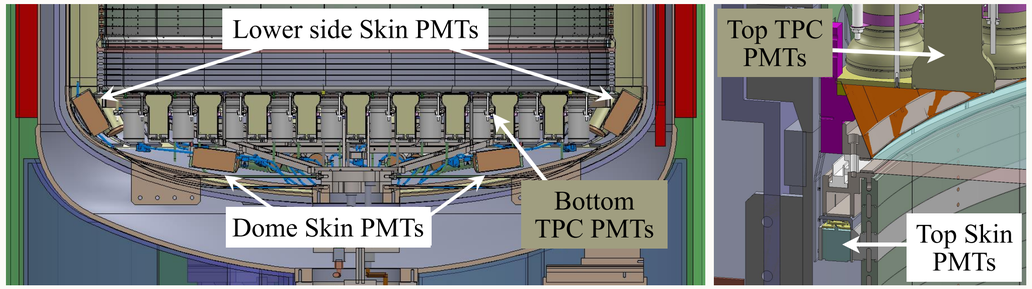




The LZ veto system: Skin+OD

Skin detector

Main purpose: veto Compton recoils from ~MeV radiogenic γ-rays



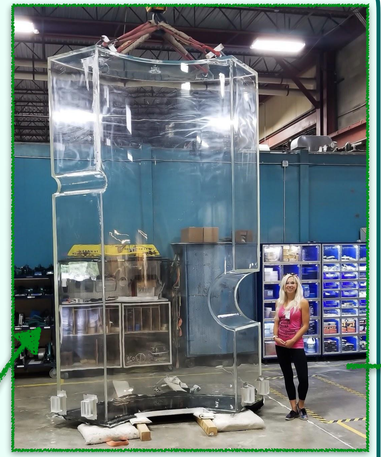
Comprises: 2t-LXe region between TPC outer walls and inner cryostat vessel: → 93 PMTs at the top and 38 PMTs at the bottom

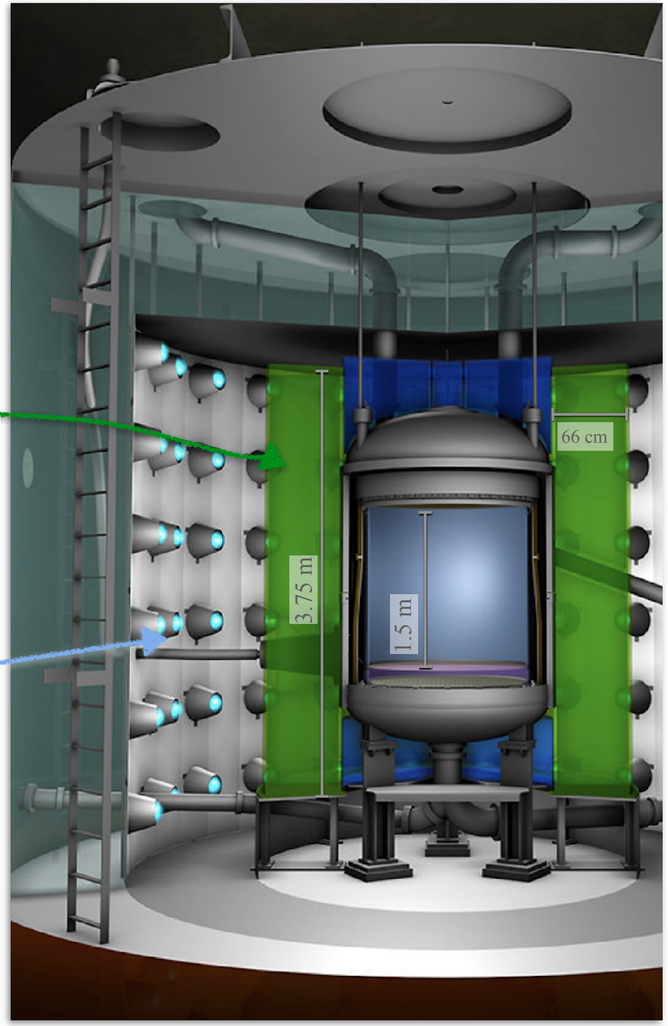
Outer detector (OD)

Main purposes:
- active muon and internal neutrons veto
- passive external neutron veto

Comprises:

1. 10 UV-transparent acrylic tanks with 17t of Gd-loaded liquid scintillator to increase n-capture efficiency
2. A tank filled with ~238t of ultra-pure water instrumented with 120 8-inch PMTs

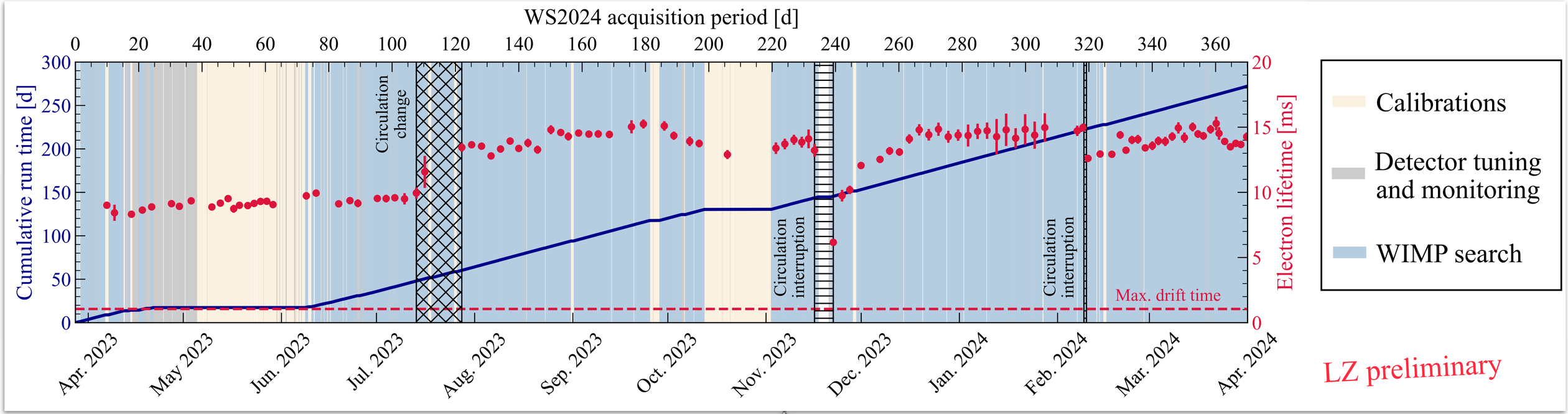




WIMP Search 2024 (WS2024)

PRL 135, 011802 (2025)
Announced on 26/08/24

- Pre-WS2024: successful (60d) first run: **WS2022**, provided world-leading Dark Matter result PRL 131, 041002 (2023)
- After detector optimisation and calibration: **WS2024**
- **220 live-day exposure**: data from March 2023 to end March 2024
  - Several calibrations before and during run to correct for spatial/temporal effects
  - Very stable run conditions: e.g. >8 ms e^- lifetime
  - >95% data-taking uptime during science operation (before data-quality and lifetime exclusions)



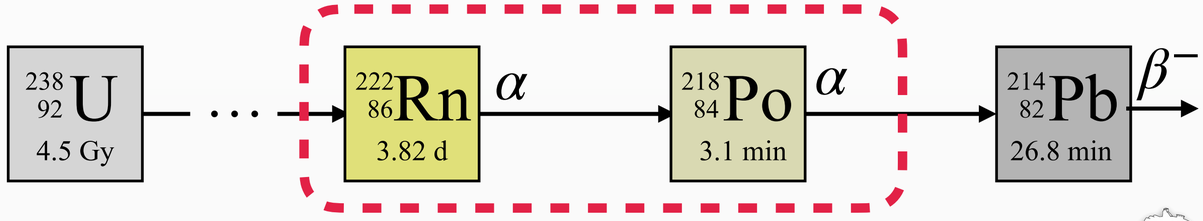
NEW FEATURE

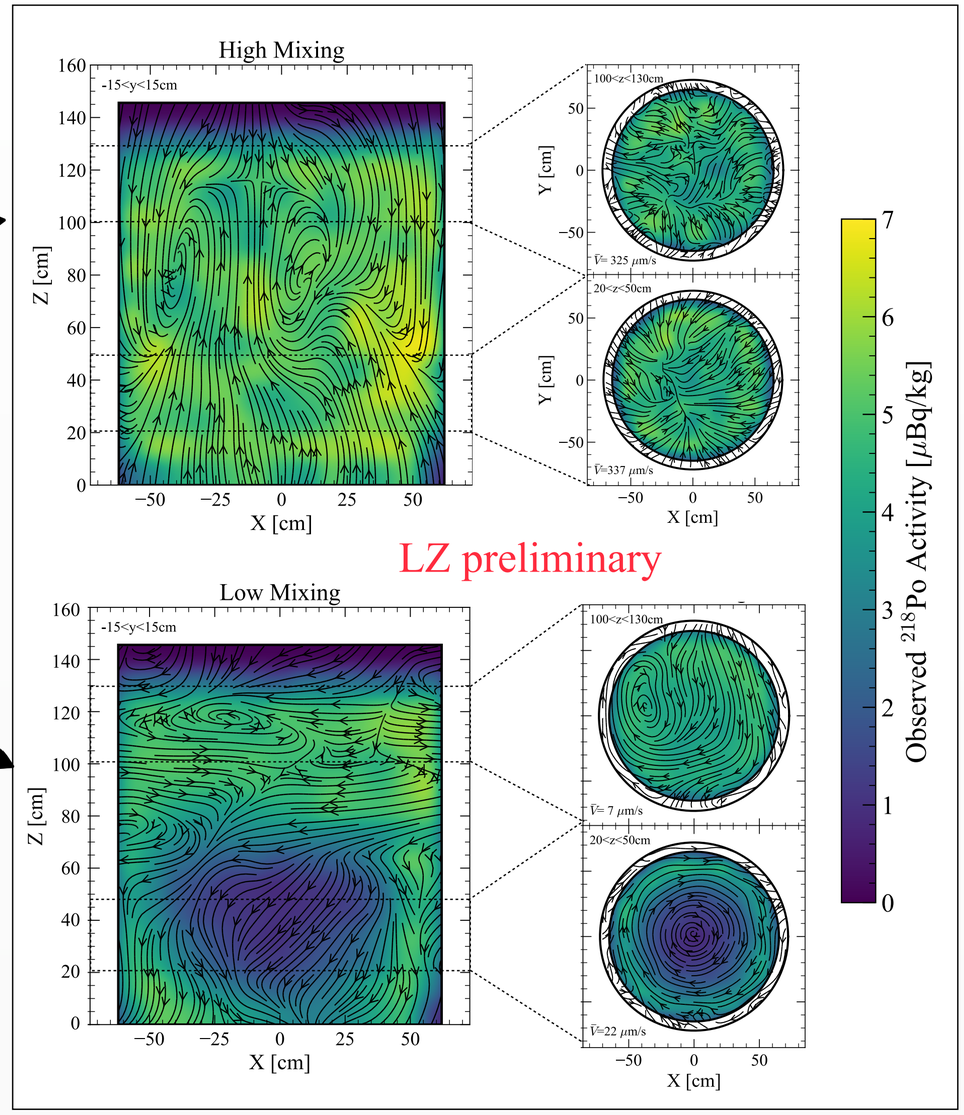
Xenon flow in the TPC: Radon tag

arXiv:2508.19117v1

- "Naked" ^{214}Pb β decay is the biggest ER background
- Excellent control of temperature and xenon flow
- WS2024 data acquired in two different flow states:
  1. **High-mixing**: turbulent flow → uniform distribution of injected calibration sources
  2. **Low-mixing**: distinct regions of laminar flow → possibility to map the fluid velocity field

- Coincident ^{222}Rn(^{238}U chain)-^{218}Po α decays (^{218}Po $T_{1/2}$ = 3.1 min) to map the fluid velocity field



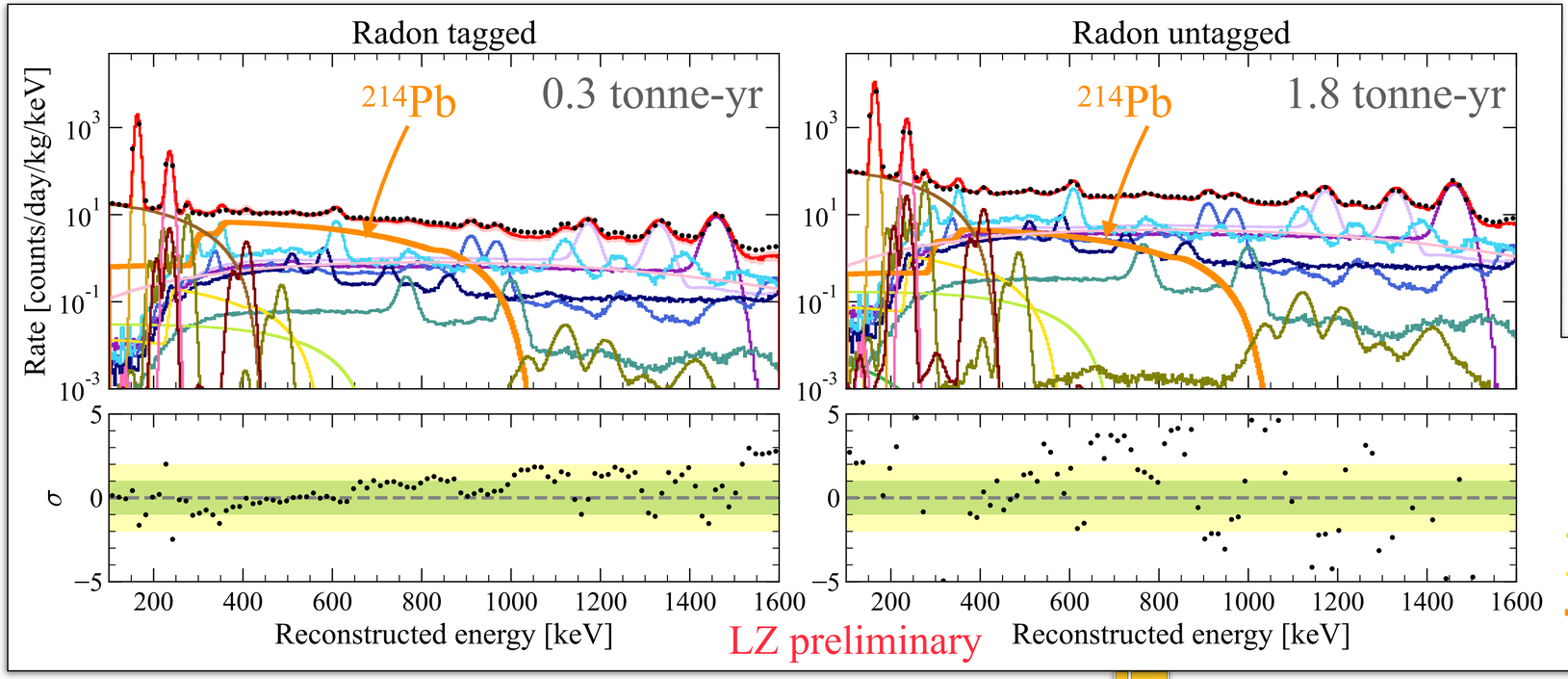


NEW FEATURE

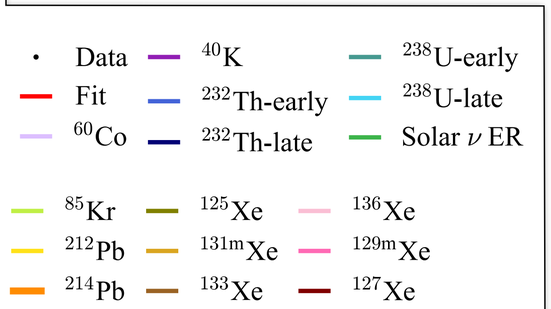
Xenon flow in the TPC: Radon tag

arXiv:2508.19117v1

- "**Radon tag**" to identify events with high likelihood of being ^{214}Pb decays. Based on simulations of neutral and charged progenies using these velocity fields during low-mixing state
  - ➡ Tag volume defined for each identified ^{218}Po α decay along streamlines for $3\times T_{1/2}(^{214}\text{Pb})$
- ^{214}Pb in untagged subsample 1.8±0.3 μBq/kg (3.9±0.6 μBq/kg in total exposure → ~60% reduction)
- Both tagged and untagged data included in WIMP analysis → no "loss of exposure"



	% of total ^{214}Pb	% of exposure
Tagged	60 ± 4	15
Untagged	40 ± 4	85

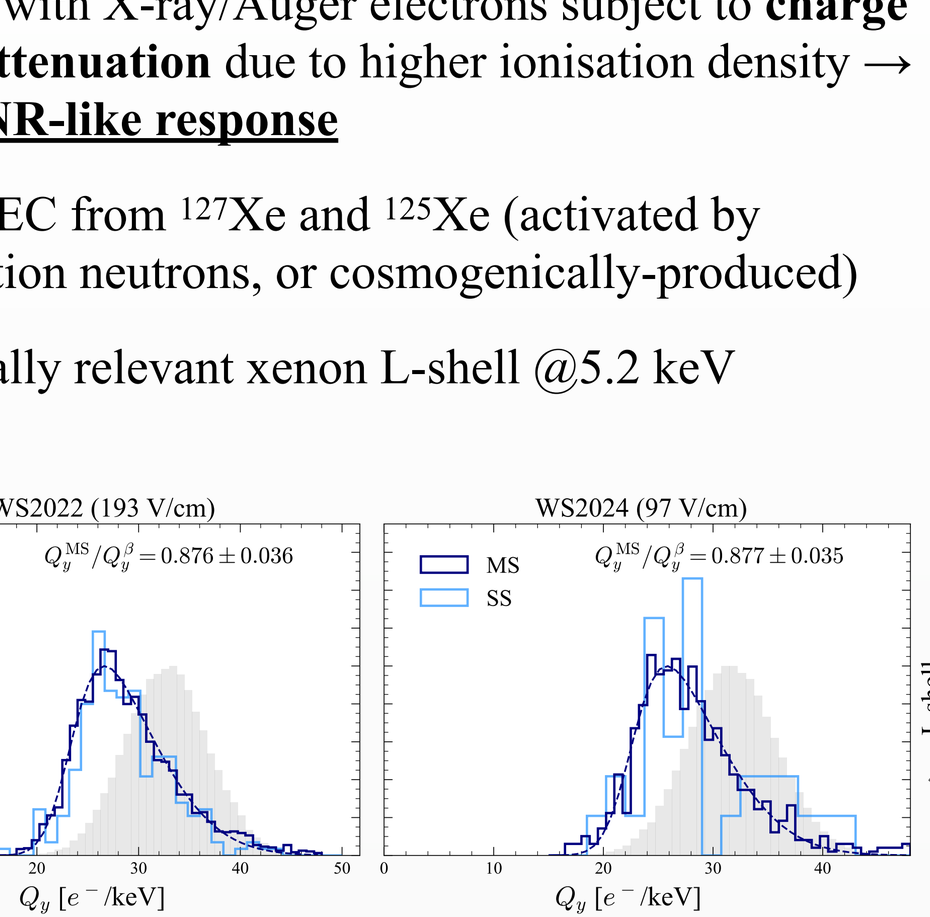


NEW FEATURE

PRD 112, 012024 (2025)

Electron Capture (EC) Decay Backgrounds

- Events with X-ray/Auger electrons subject to **charge yield attenuation** due to higher ionisation density → **more NR-like response**
- In LZ, EC from ^{127}Xe and ^{125}Xe (activated by calibration neutrons, or cosmogenically-produced)
- Especially relevant xenon L-shell @5.2 keV



→ Same energy deposited, different event topology

- In-situ LZ measurement with WS2024 data (at 97 V/cm)
- Using MS event selection:

$Q_L/Q_\beta = 0.877 \pm 0.035$

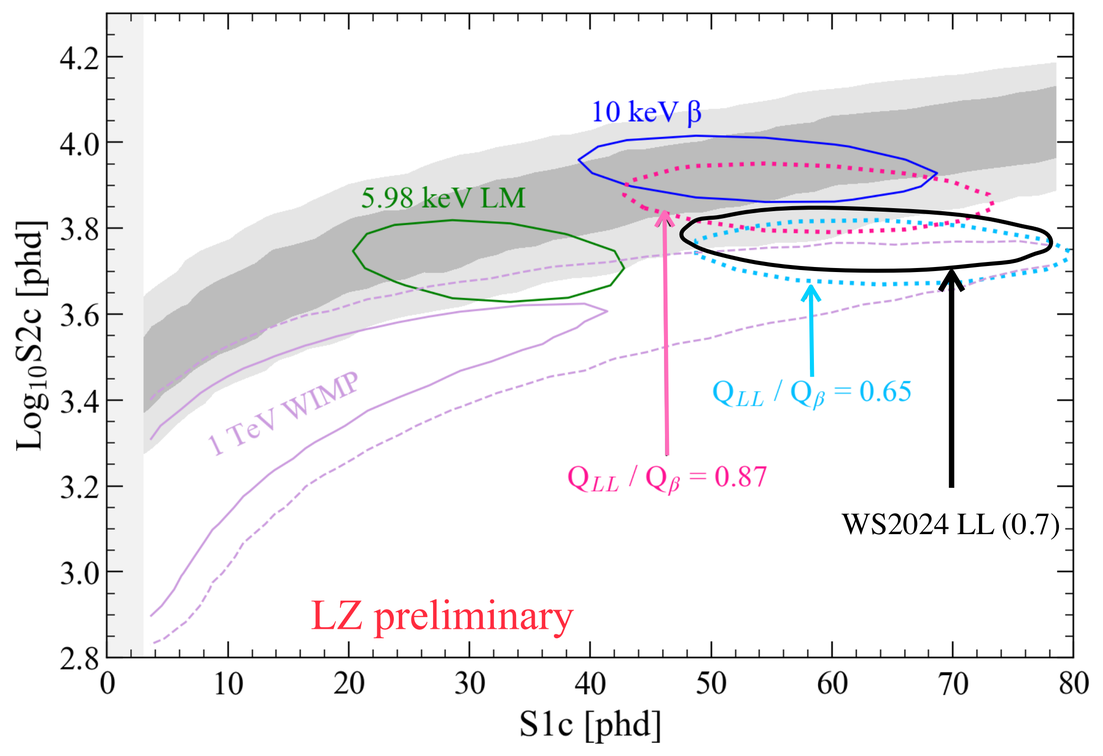
NEW FEATURE

PRD 112, 012024 (2025)

EC Decay Backgrounds: ^{124}Xe DEC

- ^{124}Xe two-neutrino DEC measured by LZ: $T_{1/2} = (1.09 \pm 0.15(\text{stat}) \pm 0.05(\text{syst}) \times 10^{22})$ yr
- LM (6.0 keV) & LL (10.0 keV) shells relevant for WS

J. Phys. G: Nucl. Part. Phys. 52 015103 (2025)



- Expect 7.1 (LM) + 12.3 (LL) = 19.4 counts
- LM modelled similarly as single L-shell charge suppression
- Expect LL captures to display further charge yield suppression
- Background model allows LL-capture to float in the final fit:

$0.65 < Q_{LL}/Q_\beta < 0.87$ ← Q_L/Q_β

2x L-shell ionisation density

Best fit value: 0.70 ± 0.04

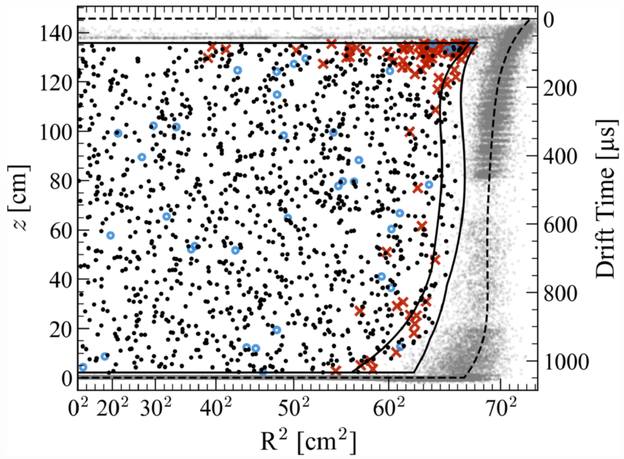
Analysis cut summary

- Cuts developed on non-WIMP ROI data. Include:

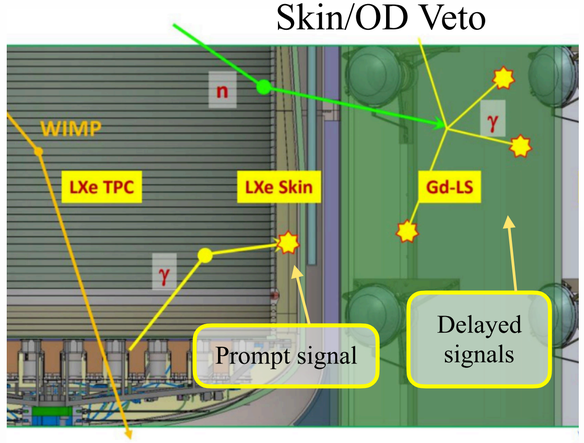
  - Single Scatter (**SS**) events
  - Region of interest (**ROI**) used:
    - S1 (>3 PMT) ROI: $3 < S1c < 80$ phd
    - S2 ROI: $\begin{cases} 645 \text{ phd } (\equiv 14.5 \text{ electrons}) < S2 \\ \log_{10}(S2c) < 4.5 \end{cases}$
  - **Time exclusions:** periods of high-rate, detector instability, hold-off after large S2s → 86% livetime retention
  - **S1-** and **S2-based cuts** (target pulse accidentals)
  - **Fiducial Volume** cut (**5.5 ± 0.2 t**)
  - Events not **tagged** by **Skin** (x) or **OD** (o) in prompt/ delayed time window optimised to tag γ-rays and neutrons

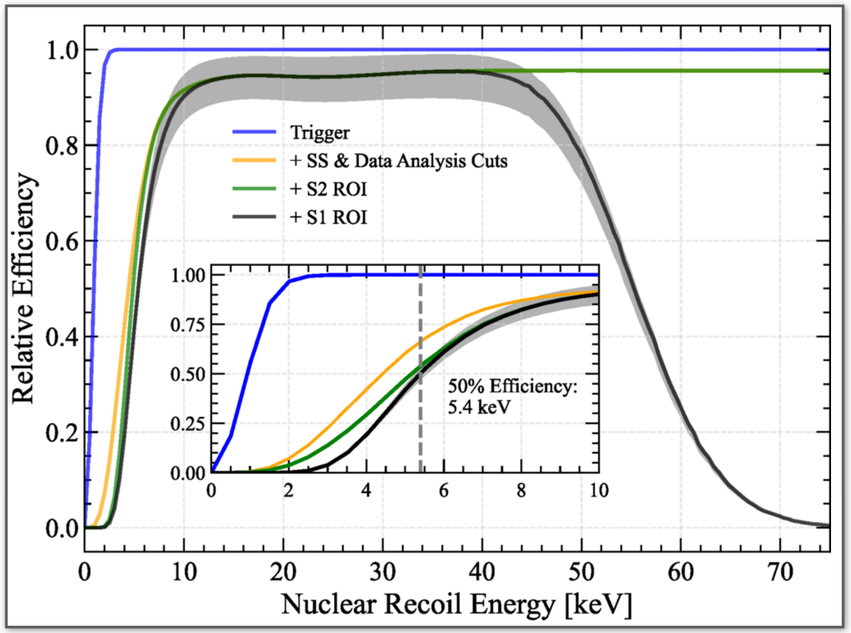
- Efficiency of cuts vs NR energy:

Fiducial Volume & vetoed events



Skin/OD Veto

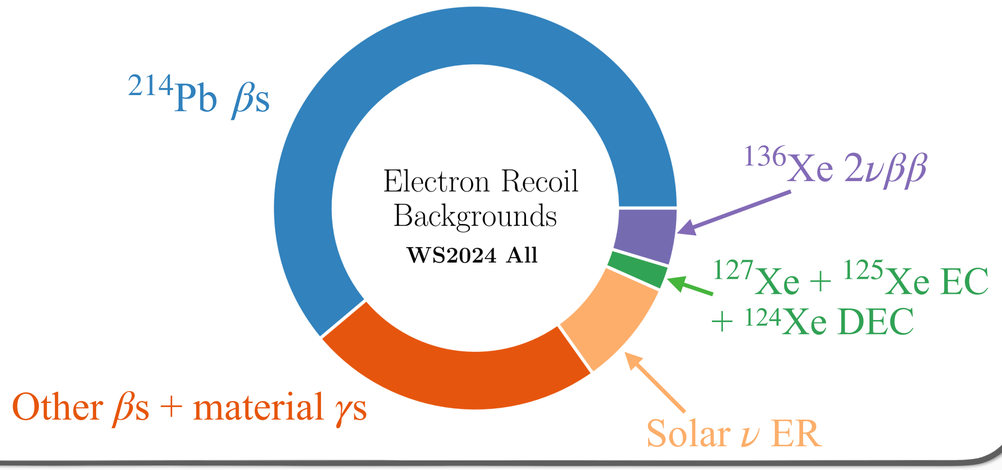




Background model

ER backgrounds

- Dissolved β emitters:
  - **^{214}Pb** (^{222}Rn), ^{212}Pb (^{220}Rn), ^{85}Kr, ^{136}Xe (ββ)
- Disolved EC decays (x-rays/Auger cascades):
  - $^{127/125}$Xe from neutron calibration activation
  - ^{124}Xe double EC
- Solar pp and ^{7}Be neutrinos
- Long-lived gamma emitters in detector materials:
  - ^{238}U chain, ^{232}Th chain, ^{40}K, ^{60}Co



Expected ER counts in WS2024 exposure: **1207**

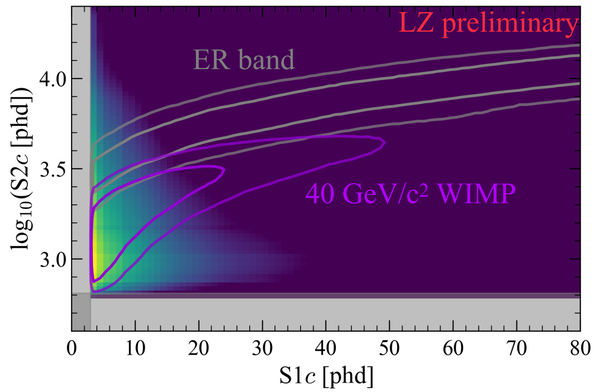
NR backgrounds

- Neutrons from spontaneous fission (SF) and (α,n) reactions in detector materials
- Solar ^{8}B and hep neutrinos (CEvNS)

Expected NR counts in WS2024 exposure: **0.18**

Instrumental backgrounds

- Accidental coincidences (uncorrelated S1/S2 pulses),



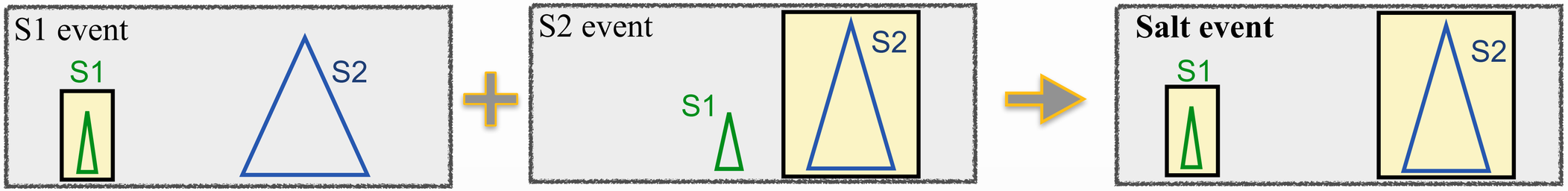
Data-driven accidentals PDF

Rate derived from Unphysical Drift Time events

Expected ER counts in WS2024 exposure: **2.8**

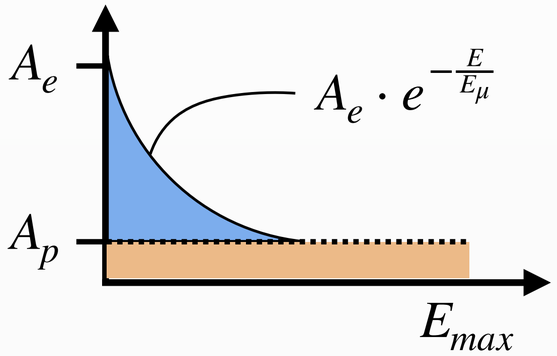
Experimenter bias mitigation: salting

- "*Salting*": injecting a random number of fake signal events during science data collection
  - ➡ How? Events manufactured by combining S1s & S2s signals from sequestered calibration data



  - ➡ Which energy? Exponential distribution that represents WIMP scattering (of randomly selected mass → $E_\mu \propto m_\chi$) + flat pedestal to higher energies (A_p) for higher NR energies analyses
  - ➡ How many? Enough to obscure any bias, but not so many as to overwhelm any pathological events in the real data: random number between

$$\mathbf{[0, \mathit{N}]}, \quad \mathit{N} \text{ from WS2022 upper limit}$$



Identity revealed after analysis input are finalised for final statistical inference

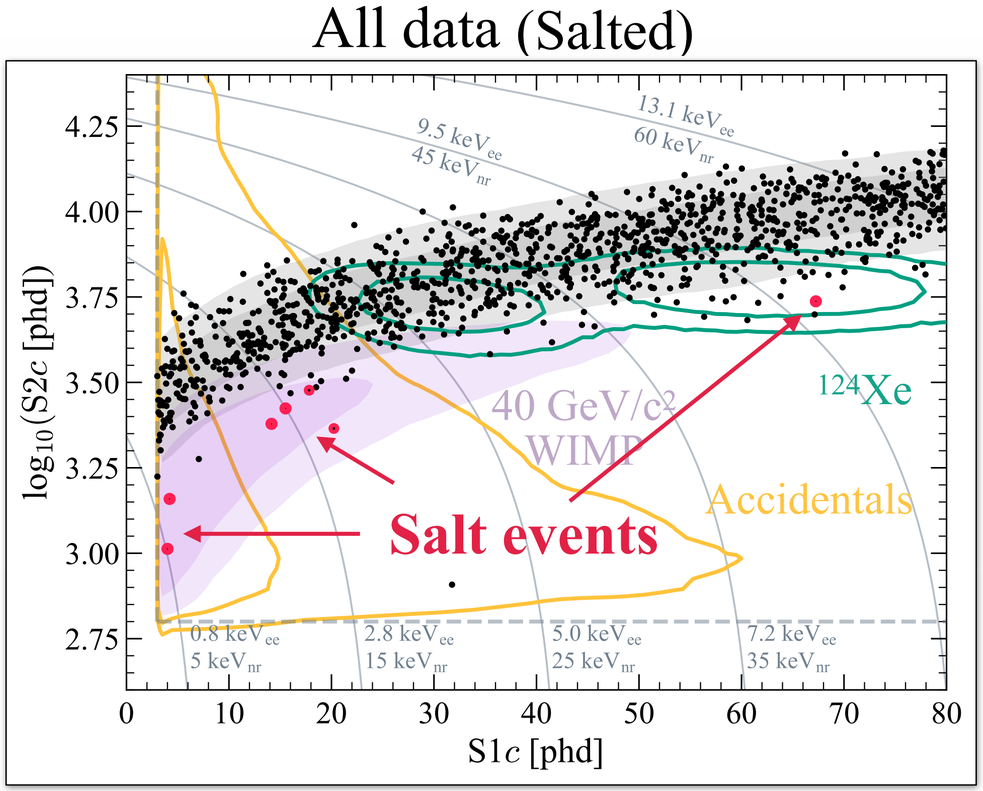
$$A_e = \alpha \times N$$
$$A_p = 1 - A_e$$

WS2024 Final Dataset

- 8 salt events revealed → **7 of which pass all analysis cut** (consistent with evaluated signal efficiency)
- **1220** events remain after unsalting
- No post-unsalting changes to model
- Final exposure:

  220 live days x 5.5 tonnes = **3.3 tonne yr**

- Statistical analysis in observed S1*c*-$\log_{10}$(S2*c*) space
- Likelihood fed with 6 subsamples: WS2024 (with 4 Rn-tag configurations), Skin/OD veto sideband, WS2022



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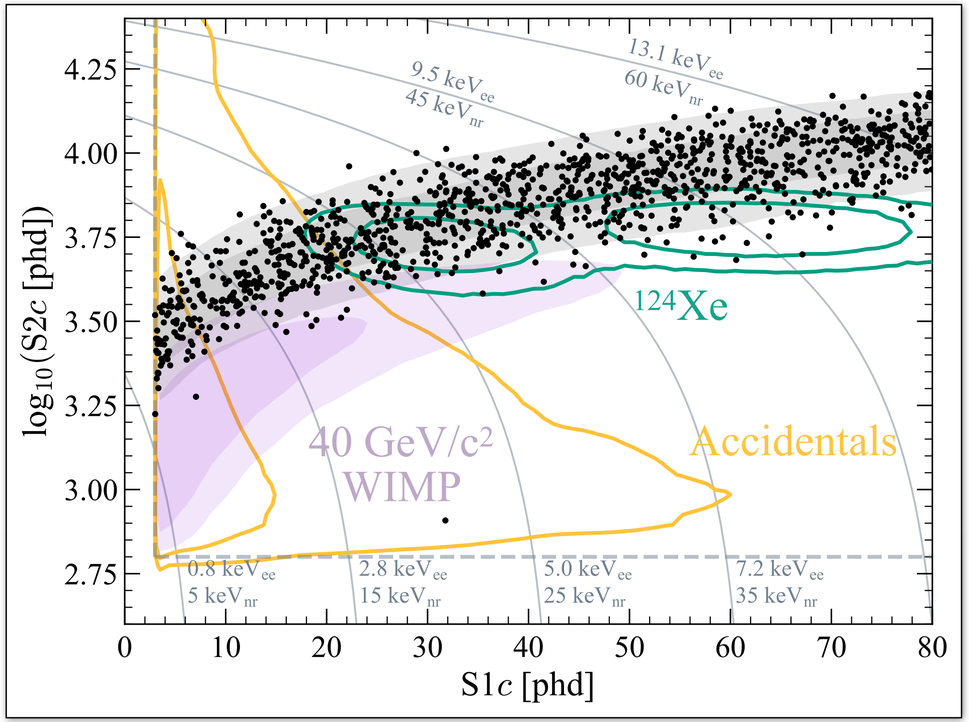
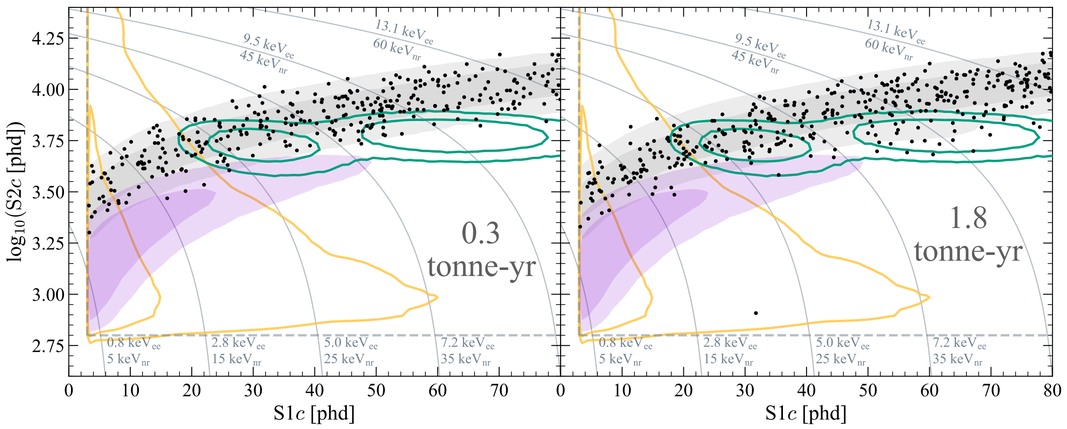
All data

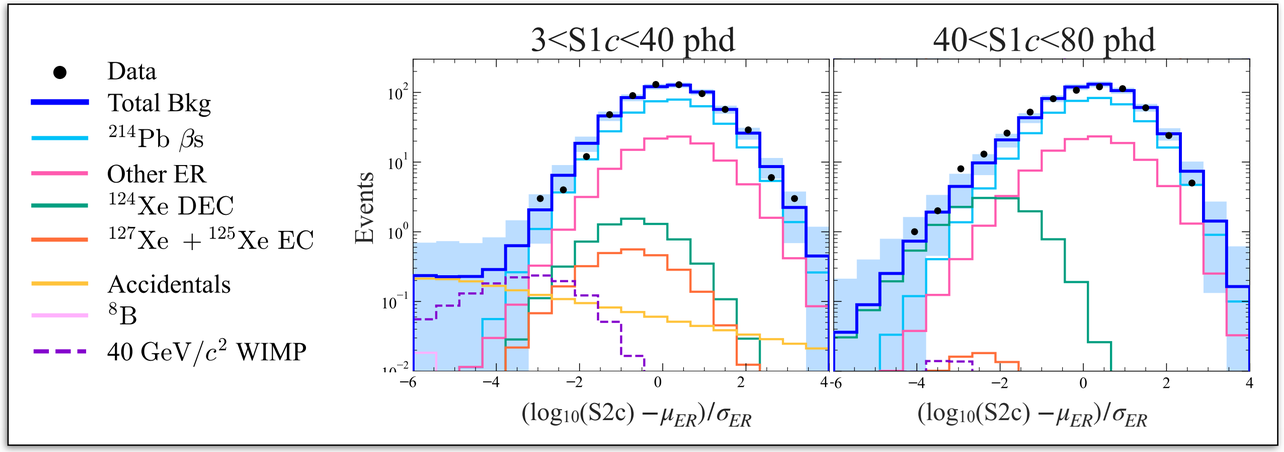


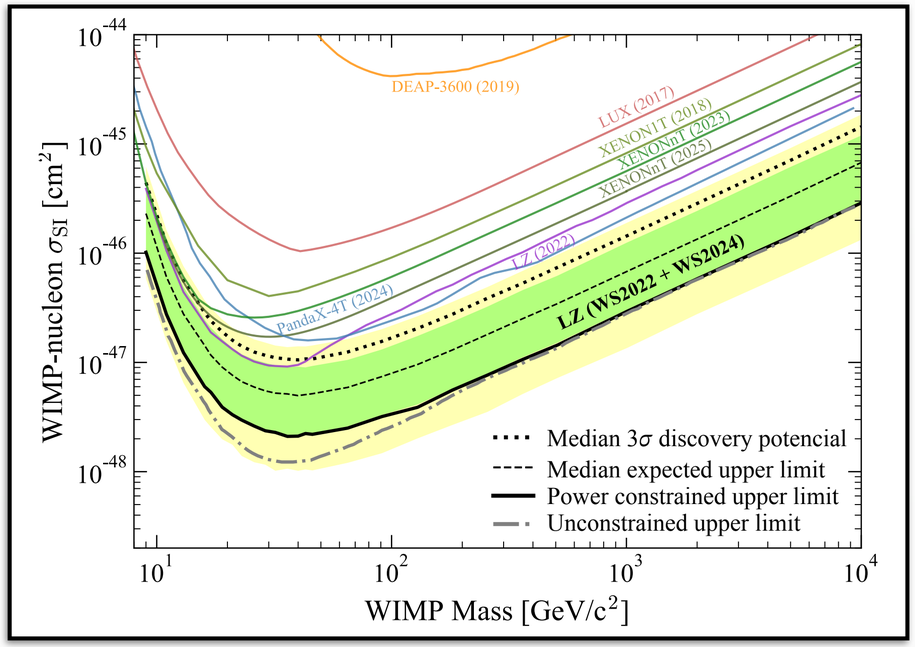
Radon-Tagged subsample

Radon-Untagged subsample



WS2024+WS2022 Fit result and SI limits



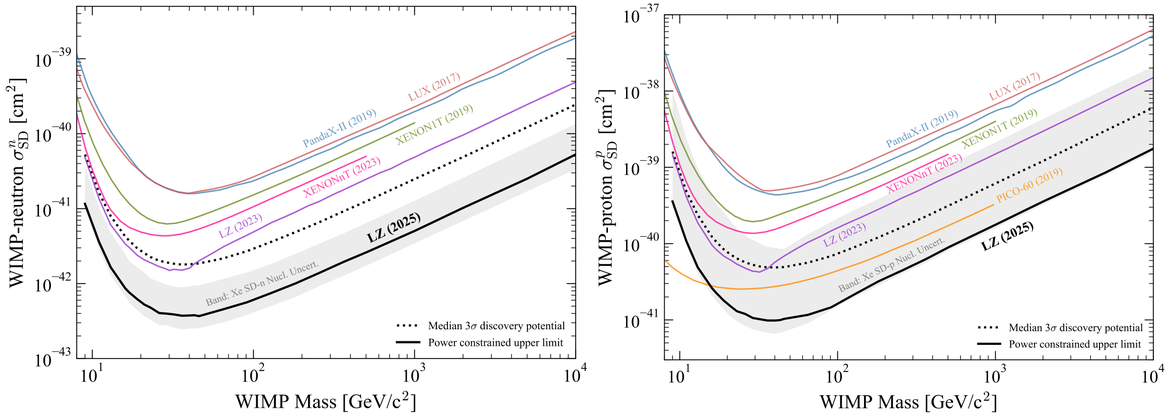


- Good data/model agreement in all spaces
- Best fit of **zero WIMPs** at all tested masses (9 GeV/c² - 100 TeV/c²)
- Two-sided unbinned profile likelihood ratio test statistic
- Upper limit power constrained at -1σ sensitivity band (as DM conventions EPJC 81 907 (2021))
- Under fluctuations from distribution of accidental events in WIMP region (in WS2024) + ER under fluctuation in WS2022

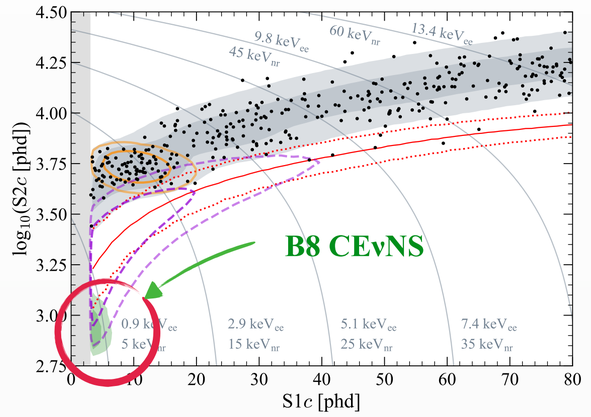
WS2024+WS2022 combined minimum limit: **2.2 x 10^{-48} cm² at 43 GeV/cm²**

Other LZ results and prospects

- Similar analysis to search for Spin-Dependent (SD) WIMP-nucleon interactions. Two limiting cases considered: WIMP-neutron, and WIMP-proton



- Atmospheric millicharge particles [PRL 134, 241802 (2025)]
- WIMP-pion [Commun Phys 7, 292 (2024)]
- Cosmic ray-boosted Dark Matter [PRL 134, 241801 (2025)]
- Covariant EFT [PRL 133, 221801 (2024)]
- And more on the horizon… exploring other energy ranges:
  - Low-mass WIMPs / B8 neutrinos via CEvNS
  - Neutrinoless Double Beta Decay



See E. Jacquet talk on Wednesday!!

- Further into the future, much larger exposures needed to fully cover the space parameter until the neutrino fog …

arXiv:2410.17137

60-80 t LXe TPC
LZ+XENON+DARWIN
~500 people / 72 institutions

Conclusions & Prospects

WIMP search 2024

- LZ is the world's most sensitive WIMP direct detection experiment:

  New world-leading WIMP search limits using WS2024+WS2022 4.2 tonne year exposure

- **2.2 x 10^{-48} cm² at 43 GeV/cm²** , exceeding previous best constraints by **>4** times
- Radon-tag technique developed and exploited for the first time in a dark matter result, reducing 60% the primary ER background
- First observation of suppressed charge yield from LL-shell captures of ^{124}Xe

Future

- LZ to keep taking data until 2028, with the goal of 1000 live days
- Multiple other physics searches on the horizon: ^{8}B CEvNS, neutrino less double beta decay, ER-based searches, and more!

Thank you for listening!
And to our sponsors and 38 participating institutions:

@lzdarkmatter

- Black Hills State University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial College London
- King's College London
- Lawrence Berkeley National Lab.
- Lawrence Livermore National Lab.
- LIP Coimbra
- Northwestern University
- Pennsylvania State University
- Royal Holloway University of London
- SLAC National Accelerator Lab.
- South Dakota School of Mines & Tech
- South Dakota Science & Technology Authority
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US Europe Asia Oceania

LZ Collaboration Meeting at SURF, June 2023